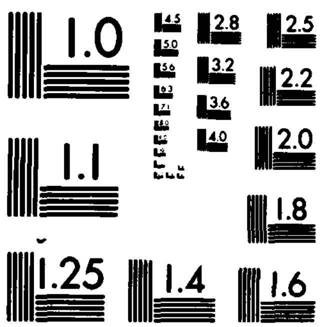
AD-A089 722 SYSTEMS SCIENCE AND SOFTWARE LA JOLLA CA F/G 18/3
THE FREQUENCY VERSUS LENGTH RESPONSE FOR A DEFORMED SLIFER CABL--ETC(U)
FEB 80 M A GROETHE, W G GINN DNA001-79-C-0099
UNCLASSIFIED SSS-R-80-4374 DNA-5241T NL

END
DATE
FILMED
11-80
DTIC



MICROCOPY RESOLUTION TEST CHART

NATIONAL BUREAU OF STANDARDS-1963-A

(12) LEVEL II

B S

DNA 5241T

AD A089722

THE FREQUENCY VERSUS LENGTH RESPONSE FOR A DEFORMED SLIFER CABLE

Systems, Science and Software
P.O. Box 1620
La Jolla, California 92038

February 1980

Topical Report for Period June 1979—December 1979

CONTRACT No. DNA 001-79-C-0099

APPROVED FOR PUBLIC RELEASE;
DISTRIBUTION UNLIMITED.

THIS WORK SPONSORED BY THE DEFENSE NUCLEAR AGENCY
UNDER RDT&E RMSS CODE B345079462 J24AAXYX98366 H2590D.

Prepared for
Director
DEFENSE NUCLEAR AGENCY
Washington, D. C. 20305

Destroy this report when it is no longer needed. Do not return to sender.

PLEASE NOTIFY THE DEFENSE NUCLEAR AGENCY, ATTN: STTI, WASHINGTON, D.C. 20305, IF YOUR ADDRESS IS INCORRECT, IF YOU WISH TO BE DELETED FROM THE DISTRIBUTION LIST, OR IF THE ADDRESSEE IS NO LONGER EMPLOYED BY YOUR ORGANIZATION.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: DNA 5241T

2. GOVT ACCESSION NO.: AD-A089722

3. RECIPIENT'S CATALOG NUMBER:

4. TITLE (and Subtitle): THE FREQUENCY VERSUS LENGTH RESPONSE FOR A DEFORMED SLIFER CABLE

5. TYPE OF REPORT & PERIOD COVERED: Topical Report for Period Jun [redacted]—Dec [redacted] 79

6. PERFORMING ORG. REPORT NUMBER: SSS-R-80-4374

7. AUTHOR(s):
Mark A. Groethe
Warren G. Ginn

8. CONTRACT OR GRANT NUMBER(s): DNA 001-79-C-0099

9. PERFORMING ORGANIZATION NAME AND ADDRESS:
Systems, Science and Software
P.O. Box 1620
La Jolla, California 92038

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: Subtask J24AAXYX983-66

11. CONTROLLING OFFICE NAME AND ADDRESS:
Director
Defense Nuclear Agency
Washington, D.C. 20305

12. REPORT DATE: Feb [redacted] 980

13. NUMBER OF PAGES: 28

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office):

15. SECURITY CLASS (of this report): UNCLASSIFIED

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE:

16. DISTRIBUTION STATEMENT (of this Report):

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report):

18. SUPPLEMENTARY NOTES:

This work sponsored by the Defense Nuclear Agency under RDT&E RMSS Code B345079462 J24AAXYX98366 H2590D.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number):
SLIFER
Shock Wave Velocity
Shock Wave Location
Nuclear Test Diagnostics

20. ABSTRACT (Continue on reverse side if necessary and identify by block number):

On a recent underground explosive test, an anomalous response was recorded by the SLIFER system. Several experiments were performed in an attempt to explain this behavior by introducing short, deformed sections of cable into the transmission line. The frequency versus length response of the SLIFER was then characterized for these several possible configurations. A credible explanation of the anomalies did not result from this work.

DD FORM 1473, 1 JAN 73 — EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

388 507

TABLE OF CONTENTS

Page

LIST OF ILLUSTRATIONS

I. INTRODUCTION

The Shorted Location Indicator by Frequency of Electrical Resonance, or SLIFER, method is used to measure the location of a shock front near an explosion in rock versus time.[1,2,3]

The most common SLIFER design uses a shorted transmission line as the inductive element in a Colpitts oscillator circuit. The transmission line is positioned radially from the blast source. As the shock wave moves out from the source at some velocity, u, it crushes and shorts the transmission line as shown in Figure 1. The decreasing length of shorted line reduces the inductance as seen by the oscillator and thus raises the frequency of the resonant oscillation. The determination of oscillator frequency makes possible the direct determination of the resultant cable length.

It can be shown that if,

$$0 \le \ell < \frac{\lambda}{4} = \frac{\pi}{2} \frac{V_{ph}}{\omega} ,$$

then the input impedance of a shorted transmission line can be represented best by an inductive reactance that obeys the following equation

$$L = \frac{Z_c}{\omega_\ell} \tan\left(\frac{\ell\omega_\ell}{V_{ph}}\right). \qquad (1)$$

where

L = inductance of line

Z_c = characteristic impedance of line

ℓ = initial length of the line

ω_ℓ = initial frequency of oscillator = $2\pi f\ell = 1/\lambda$ $2\pi V_{ph}$,

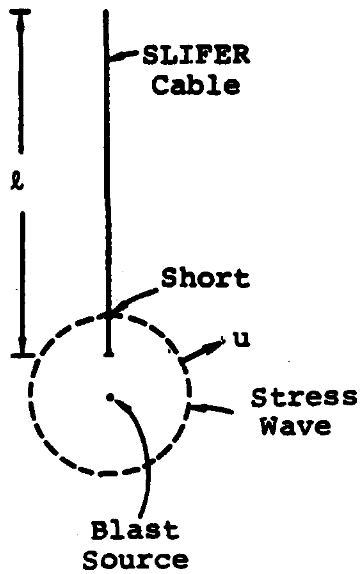


Figure 1. SLIFER cable orientation to blast source.

V_{ph} = propagation velocity of cable.

If the line is considered to be a uniform distortionless cable, then

Z_c = constant.

If the SLIFER line is taken to be the inductive element in the tank circuit of an oscillator, then the relationship between the frequency of the oscillator and the length of the shorted line is

$$x = \frac{V_{ph}}{\omega_x} \left\{ \frac{\omega_\ell \left(\omega_o^2 - \omega_x^2\right)}{\omega_x \left(\omega_o^2 - \omega_\ell^2\right)} \tan \left(\frac{\ell \omega_\ell}{V_{ph}} \right) \right\} . \qquad (2)$$

where

ω_o = the frequency of the oscillator when the length of the shorted cable is zero (it depends only on the internal inductance of the oscillator).

ω_x = The frequency of the oscillator when the length of shorted cable is x.

A curve of ω_x versus x can be constructed. If ω_x versus time is measured while the blast induced stress wave is crushing and shorting the cable, then the velocity of the stress wave can be found, since

$$\frac{dx}{dt} = \frac{d\omega_x}{dt} \frac{dx}{d\omega_x} \quad \text{and} \quad \frac{dx}{dt} = u \ . \qquad (3)$$

An anomalous effect has been observed that is inconsistent with this theory. On a recent event the SLIFER cables were run in the vicinity of the LOS pipe as shown in Figure 2. ω_x versus time was measured, and a discontinuity in ω_x was observed corresponding to an instantaneous decrease in cable length near the muffler region, see Figure 3.

It is possible that the transmission line experiences a deformation of some sort in the muffler region when the

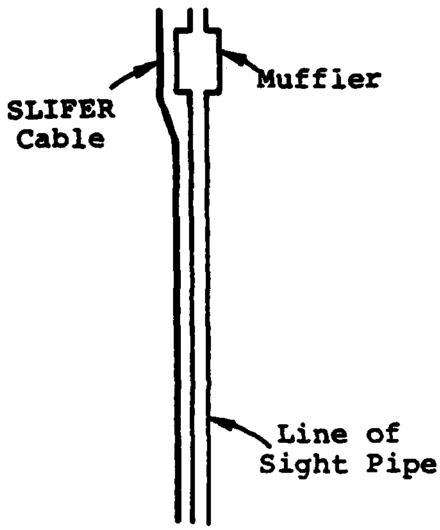


Figure 2. SLIFER cable along LOS pipe.

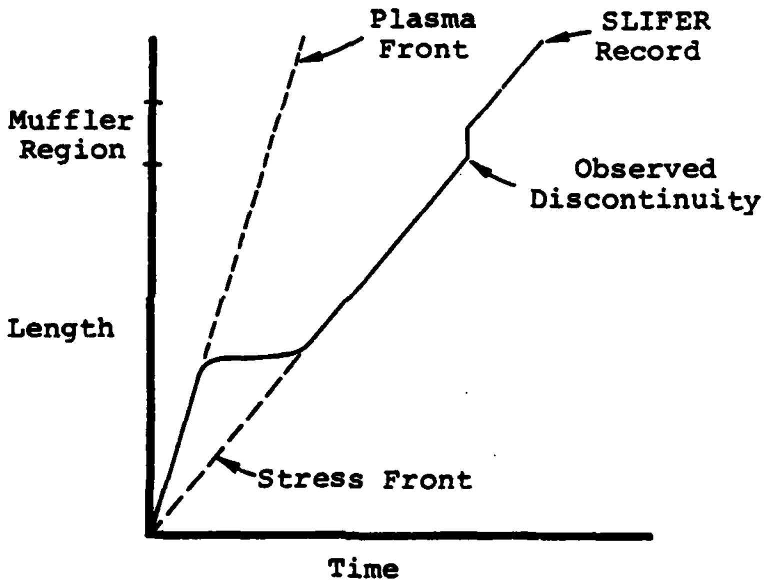


Figure 3. Qualitative features of the observed SLIFER record.

plasma front moving up the pipe enters the muffler. Shocks may be induced in the surrounding grout causing deformations or some other type of damage to the cable, see Figure 4. As the stress wave passes over the deformed section at a later time, a discontinuous increase in frequency occurs or correspondingly, an apparent discontinuous decrease in cable length is observed. A series of experiments has been done to investigate the credibility of this suggestion. A SLIFER oscillator and length of cable were kindly made available to us by R. C. Bass of Sandia Corporation.

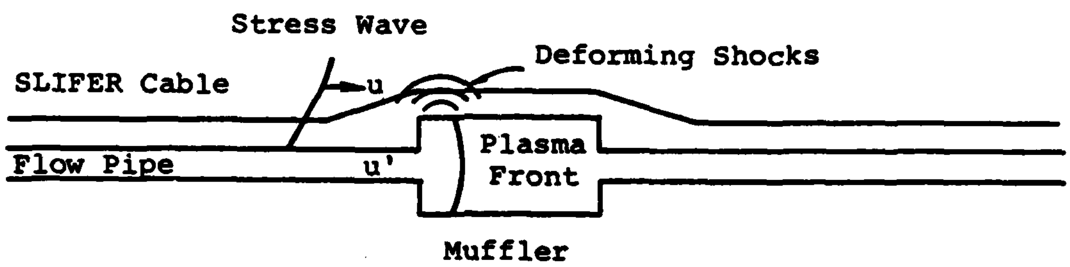


Figure 4. Plasma front induced deforming shocks.

II. THEORY

In order to estimate the effects of any deformations we can represent a deformed cable as follows.

Once the deformation has occurred, the SLIFER line consists of three segments, a deformed segment between two coaxial segments as shown in Figure 5.

In the event under consideration, the observed frequency change was 13 KHz occurring at $x_1 \approx 16$ m. The initial SLIFER cable length was about 61 m. Also, no discernible slope existed for the discontinuity which implies that the deformed section, $x_2 - x_1$, was very short, on the order of centimeters.

In the situation considered here, the length of the deformed section is very small compared to the wavelength of the oscillator signal, which is typically about 200 m to 300 m; therefore, it can be represented by discrete reactive elements. A cable containing discrete elements at one quarter wavelength intervals is commonly referred to as a "loaded line".[4] The added capacitance or inductance is considered to be uniformly distributed over the rest of the line.

If L_1 and C_1 are the inductance and capacitance per unit length for a normal cable, and L_2 and C_2 are that for the deformed line, then for $x_2 \leq x \leq x_3$ the effective inductance and capacitance per unit length is,

$$L' = L_1 \left(\frac{x_1 + x - x_2}{x} \right) + L_2 \left(\frac{x_2 - x_1}{x} \right) \tag{4}$$

$$C' = C_1 \left(\frac{x_1 + x - x_2}{x} \right) + C_2 \left(\frac{x_2 - x_1}{x} \right) \quad . \tag{5}$$

For $x_1 \leq x \leq x_2$,

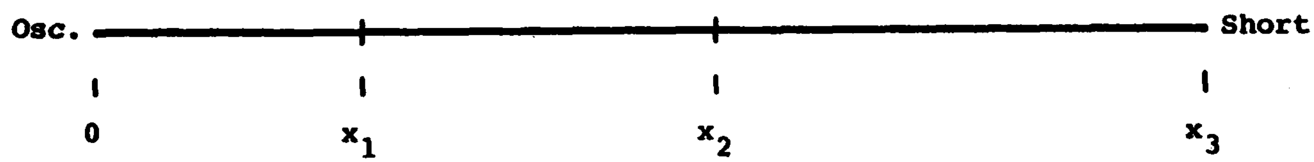


Figure 5. Model for the deformed SLIFER cable.

$$L' = L_1 \left(\frac{x_1}{x}\right) + L_2 \left(\frac{x - x_1}{x}\right) \tag{6}$$

$$C' = C_1 \left(\frac{x_1}{x}\right) + C_2 \left(\frac{x - x_1}{x}\right) \tag{7}$$

and, finally, for $x \leq x_1$,

$$L' = L_1 \tag{8}$$

$$C' = C_1 \ . \tag{9}$$

The changing effective inductance and capacitance per unit length will alter the effective characteristic impedance and phase velocity of the line.

$$Z_c' = \left(\frac{L'}{C'}\right)^{1/2} \tag{10}$$

$$V_{ph}' = \frac{1}{c} \left(\frac{1}{L' \cdot C'}\right)^{1/2} \tag{11}$$

where c is the velocity of light. These values can be substituted into a modified form of Eq. (2) that takes into account the characteristic impedance of the cable.

$$x = \frac{V_{ph}'}{\omega_x} \arctan \left\{ \frac{Z_c}{Z_c'} \frac{\omega_\ell}{\omega_x} \frac{\left(\omega_o^2 - \omega_x^2\right)}{\left(\omega_o^2 - \omega_\ell^2\right)} \tan \left(\frac{\ell\omega_\ell}{V_{ph}}\right) \right\}. \tag{12}$$

For a co-axial cable, the inductance per unit length and capacitance per unit length are given by,

$$L = \frac{1}{\sqrt{\varepsilon}} \frac{\mu_o}{2\pi} \ell n \left(\frac{r_1}{r_2}\right) \tag{13}$$

$$C = 2\pi\varepsilon_o \frac{\varepsilon}{\ell n\left(\frac{r_1}{r_2}\right)} \tag{14}$$

where

r_1 = the radius of the outer conductor

r_2 = the radius of the center conductor

ε = the dielectric constant

ε_o = the permittivity of free space

μ_o = the permeability of free space

III. EXPERIMENTAL DESIGN

Several types of possible deformations were envisioned,

1. The outer conductor crushes.
2. The cable kinks at a mount.
3. The cable stretches such that the inner conductor "necks" down to a greater degree than the outer conductor.
4. A hole is created in the outer conductor.
5. The outer conductor severes but a conducting path, or some resistance, is formed in the grout.

A nine meter length of air dielectric, co-axial cable was sectioned into several pieces as follows,

$x_3 - x_2 = 7.55$ meters

$x_2 - x_1 = 0.05$ meter and 0.2 meter

$x_1 = 1.05$ meter.

A number of small holes were drilled at specific positions in the outer conductor. This permitted the insertion of shorting pins so that the oscillator output could be determined for each type of deformation. In addition, the oscillator output was monitored on an oscilloscope and frequency counter.

IV. DATA AND ANALYSIS

The first test consisted of crushing the cable at $x_2 - x_1$ in a vise. The observed frequency increased by about 7 KHz. By working through Eqs. (4) through (14), it can be shown that crushing a cable, in the simplest case a reduction in the outer conductor diameter, will result in an initial increase in frequency, or apparent decrease in shorted cable length. This means that as the stress wave passes over the deformed section a decrease in frequency, or apparent increase in shorted length, would occur. This is, however, contrary to what was observed in the underground test.

Kinking the cable also resulted in an increase in frequency. This is to be expected since kinking will decrease the separation between the outer and inner conductors.

A hole was cut in the outer conductor between x_2 and x_1 which resulted in a slight decrease in frequency. For a 3 cm^2 hole, the decrease was only 200 Hz. Removing the outer conductor entirely between x_2 and x_1 (a 5 cm length) and connecting a single wire in its place, see Figure 6, resulted in a frequency reduction of 3 KHz. Another possible deformation is that the outer conductor could split or sever with grout material entering the cavity between the two conductors. A current path of some resistance could be induced through the grout. This was modeled by inserting a resistance between the inner conductor and the outer conductor and also by joining the severed conductors with a resistance.

Several values of resistance were tried between the inner conductor and outer conductor; these were,

$$R = 20K\ \Omega,\ 100\ \Omega \text{ and } 10\ \Omega.$$

Figure 7 is a plot of the effect on the frequency response. The initial scatter is due to complicated waveforms that

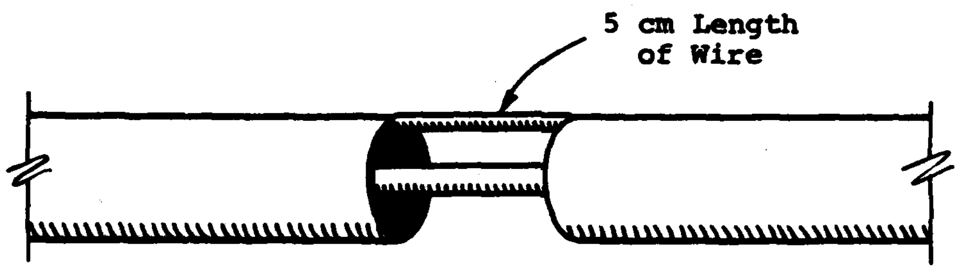


Figure 6. Deformed section bridged by a wire.

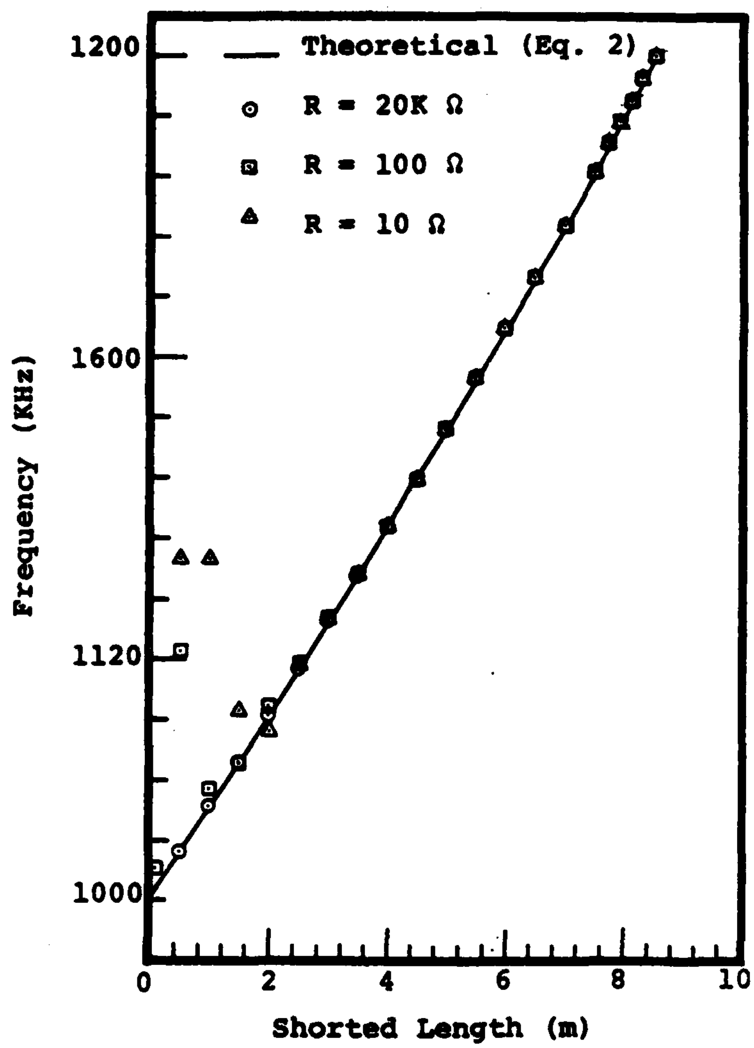


Figure 7. Frequency response of resistance connected between inner and outer conductor.

were generated by the insertion of the resistor. As the shorted length decreased, the higher order frequencies dissipated leaving only the fundamental oscillator frequency. The total effect was not consistent with that observed in the underground event. By connecting the outer conductors with a resistance, the major effect was to reduce the amplitude of the oscillator signal with a very slight change in oscillator frequency.

The final type of possible deformation considered was the "necking" down of the center conductor due to cable stretching. The outer conductor can also neck down but its final effect would only be to reduce the magnitude of the total frequency change. Therefore, only reductions in the diameter of the center conductor were considered. Two reduced diameters of the center conductor were used along with two lengths for the deformed section, see Figure 8.

Using the 5 cm length of distorted cable made a negligible change in the frequency of the oscillator for all three center conductor ratios. The results from using the 20 cm length of distorted cable is shown in Figure 9. As a/a' increases, the frequency change becomes larger.

Figure 10 gives a comparison between the experimental data points and a theoretical curve obtained from Eq. (12) for $a/a' = 40$. The theoretical curve would indicate a larger frequency change than was observed, the discrepancy is most likely due to eccentric displacement of the center conductor over the deformed section.

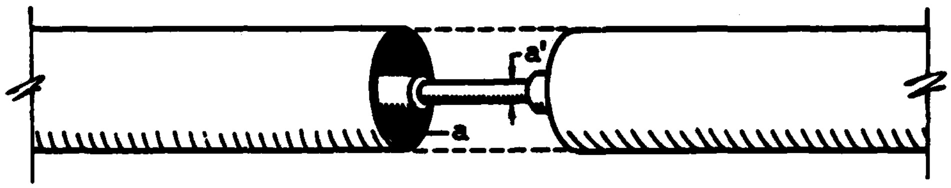


Figure 8. Reduced center conductor diameter (outer conductor over deformed section removed for clarity).

$\frac{a}{a'} = 1$, 4 and 40

$x_2 - x_1 = 5$ cm and 20 cm

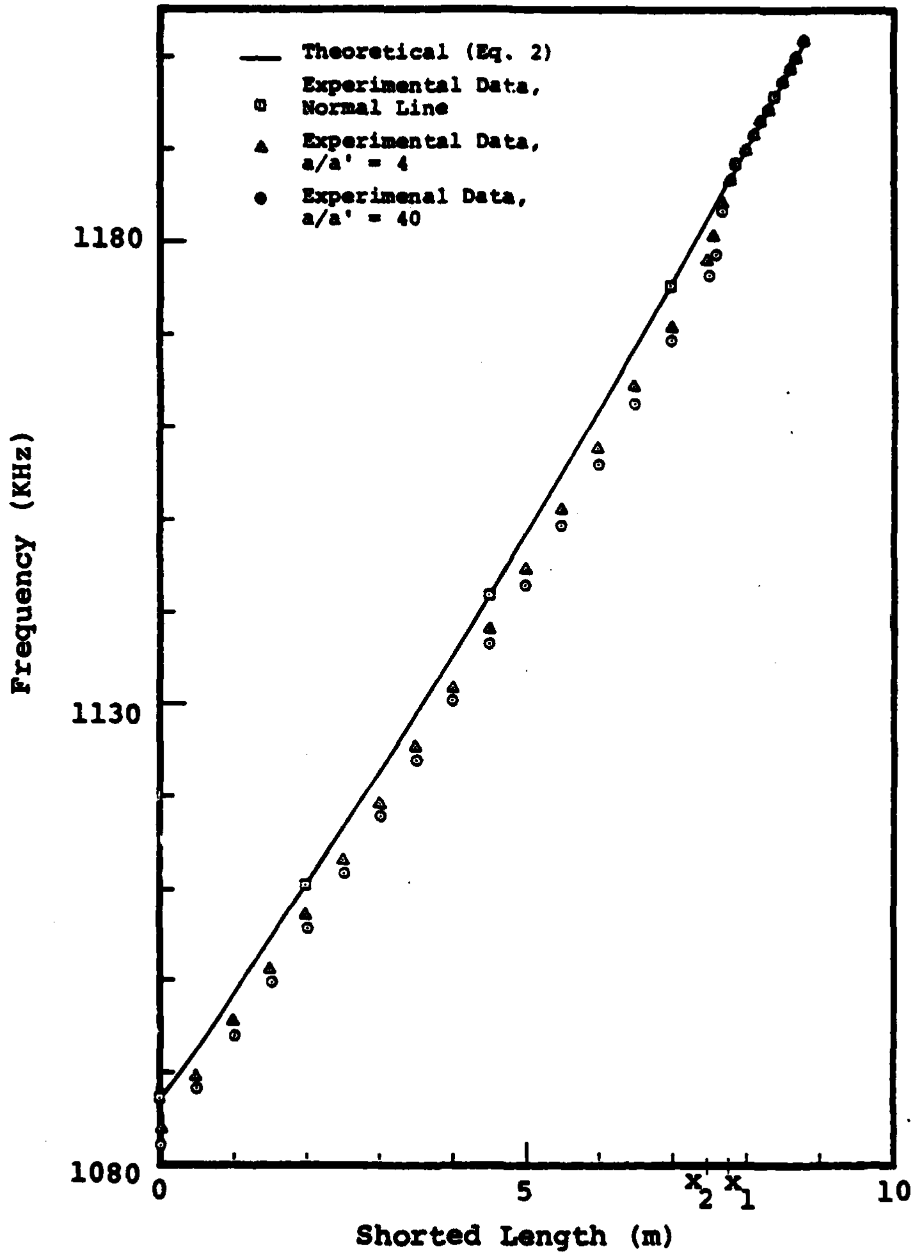


Figure 9. Frequency versus length for various center conductor diameter ratios.

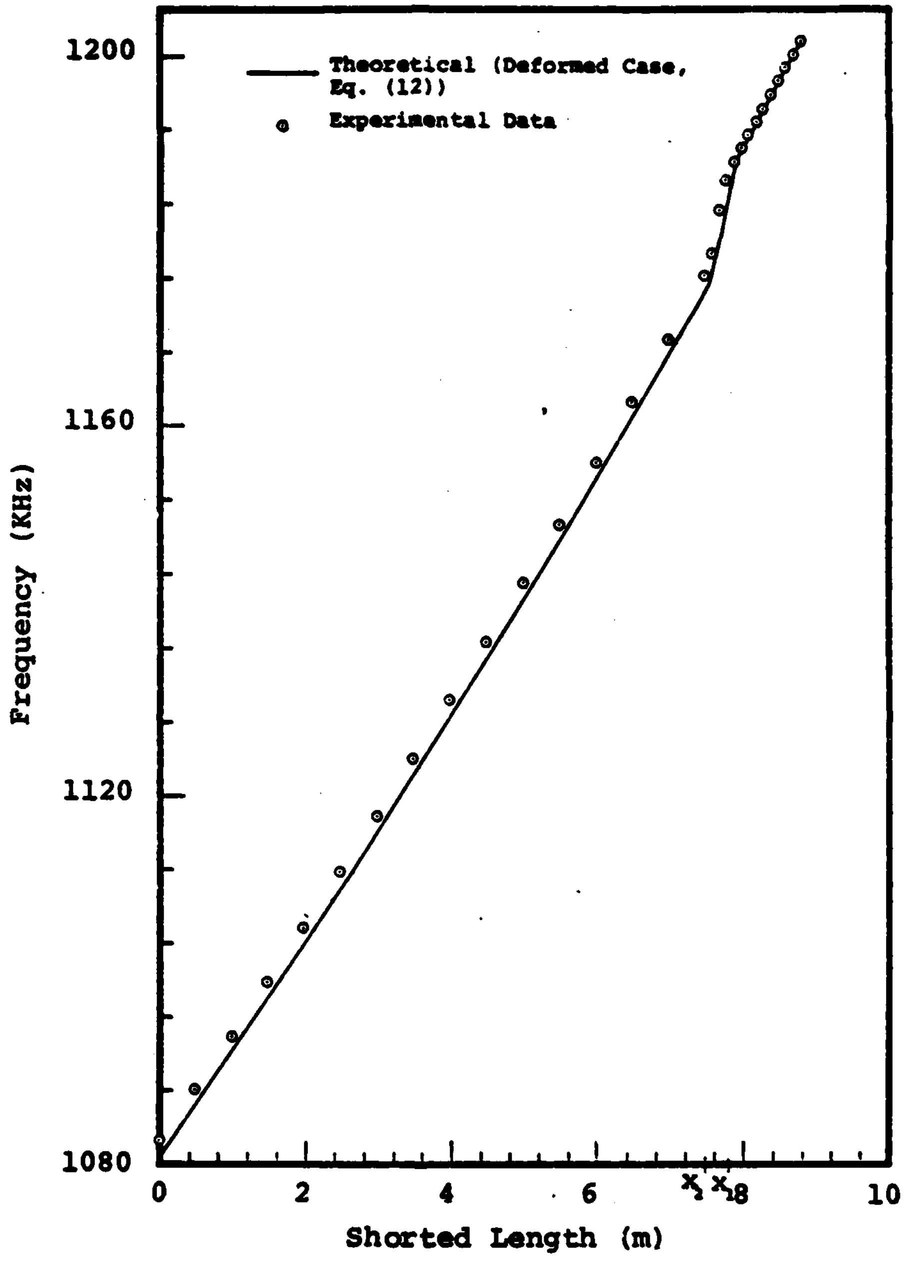


Figure 10. Comparison of predicted and experimental data for a/a' = 40.

V. CONCLUSION

Inspection of Figures 9 and 10 show that the maximum frequency change, as the deformed section is overcome, would be 4KHz for $a/a' = 4$ and 6 KHz for $a/a' = 40$. This is small compared with the frequency change of the discontinuity observed on the underground test which was about 13 KHz. Also, a very definite slope can be observed as the deformed section is traversed. No slope was detected for the observed discontinuity in the underground event. Also, Eqs. (6) through (12) show that the maximum change in frequency increases with a decreasing x_1 and/or an increasing $x_2 - x_1$. For the experimental case considered here,

$$x_1 = 1.05 \text{ meter}$$

$$x_2 - x_1 = 0.2 \text{ meter.}$$

In the observed underground event,

$$x_1 \approx 16 \text{ meters,}$$

which would imply that $x_2 - x_1$ must be much greater than 0.2 m in order that the observed maximum frequency change be the required 13 KHz. Increasing the length of the deformed section will introduce even more of a slope to the frequency change as the region is traversed. These experiments do not explain the anomalous behavior that was observed on the underground test. However, they do show that cable deformations can alter the frequency response of a SLIFER system as a function of line length. These alterations would show up as shock velocity or shock position errors.

VI. REFERENCES

1. Heusinkveld, M. and F. Holtzer, "Method of Continuous Shock Front Position Measurement," Review of Scientific Instruments, Vol. 35, No. 9, p. 1105, September, 1964.

2. Holzer, F., "Measurement and Calculations of Peak Shock-Wave Parameters from Underground Nuclear Detonations," Journal of Geophysical Research, Vol. 70, No. 1, p. 893, February 15, 1965.

3. Bass, R., B. Benjamin, H. Miller and D. Ereding, SLIFER Measurement for Explosive Yield, Sandia Laboratories, SAND 76-0007, April 1976.

4. Terman, F. E., "RADIO Engineers' Handbook," McGraw-Hill Book Company, Inc., p. 195, 1943.

Blank

DISTRIBUTION LIST

DEPARTMENT OF DEFENSE

Defense Nuclear Agency
ATTN: SPTD, T. Kennedy
4 cy ATTN: TITL

Field Command
Defense Nuclear Agency
ATTN: FCTMD, W. Summa
ATTN: FCTK, C. Keller

Field Command Test Directorate
Defense Nuclear Agency
ATTN: FCTC, J. LaComb

Defense Technical Information Center
12 cy ATTN: DD

DEPARTMENT OF ENERGY

Department of Energy
Nevada Operations Office
ATTN: R. Newman

DEPARTMENT OF ENERGY CONTRACTORS

Lawrence Livermore National Laboratory
ATTN: D. Oakley
ATTN: B. Hudson
ATTN: B. Terhune
ATTN: J. Shearer

Los Alamos Scientific National Laboratory
ATTN: R. Brownlee
ATTN: E. Jones
ATTN: F. App
ATTN: A. Davis
ATTN: L. Germain

DEPARTMENT OF ENERGY CONTRACTORS (Continued)

Sandia National Laboratories
ATTN: C. Mehl
ATTN: C. Smith
ATTN: A. Bass

OTHER GOVERNMENT AGENCY

Department of the Interior
U.S. Geological Survey
ATTN: R. Carroll

DEPARTMENT OF DEFENSE CONTRACTORS

General Electric Company—TEMPO
ATTN: DASIAC

Pacifica Technology
ATTN: G. Kent

Physics International Co.
ATTN: E. Moore

SRI International
ATTN: A. Florence

Systems, Science & Software, Inc.
ATTN: R. Duff

Terra Tek, Inc.
ATTN: S. Green

Blank